MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 2, 2015/2016

EEE2056 – PHYSICAL ELECTRONICS

(All sections/Groups)

12 MARCH 2016
2.30 p.m. - 4.30 p.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This Question paper consists of 6 pages with 4 Questions only.

2. Attempt **All** questions. All questions carry equal marks and the distribution of the marks for each question is given.

3. Please write all your answers in the Answer Booklet provided.

Useful constants and coefficients:

Physical Constants

Boltzmann's constant (k)	1.3807×10^{-23} JK^{-1} 8.617×10^{-5} eVK^{-1}
Planck's constant (h)	6.626×10^{-34} Js
Thermal voltage@300K kT/e kT	0.0259 V 0.0259 eV
Electron mass in free space (m_e)	9.10939×10^{-31} kg
Electron charge (e)	1.60218×10^{-19} C
Effective density of states in the conduction band for Si (N_c)	2.8×10^{19} cm^{-3}
Effective density of states in the Valence band for Si (N_v)	1.2×10^{19} cm^{-3}
Permeability of free space (μ_0)	$4\pi\times10^{-7}$ Hm^{-1}
Permittivity of free space of free space (ε_0)	8.85×10^{-12} Fm^{-1}
Avogadro's number (N_A)	6.022×10^{23} atoms/mol

Question 1

(a) (i) State the wave-particle duality principle and the de Broglie relationship between momentum and wavelength.

[4 marks]

(ii) The de Broglie wavelength of an electron is 115 Å. Determine the electron momentum, velocity, and energy (in eV).

[6 marks]

(iii) Using the wave equation and de Broglie relationship to derive the time-independent Schrödinger wave equation: $-\frac{\hbar^2}{2m}\frac{\partial^2\psi(x)}{\partial x^2}+V(x)\psi(x)=E\psi(x)$.

[8 marks]

(b) The quantum mechanical tunneling is intimately bound to Heisenberg Uncertainty Principle. Describe this principle and briefly discuss the application of tunneling effect in scanning tunneling microscope

[7 marks]

Continued....

Question 2

(a) In a metal, electrons interact quantum-mechanically with each other and they are restricted by the Pauli Exclusion Principle where the state of an individual electron can be described by a set of quantum numbers.

(i) Define the Pauli Exclusion Principle. [1 marks]

(ii) Define the quantum numbers and their relationships. [6 marks]

(iii) Define the Fermi-Dirac probability function and stretch the probability function of electrons distributed over the available energy states in a metal at temperature $T = 0$ K, $T_1 > 0$ K and $T_2 > T_1$. Explain your diagrams.

[7 marks]

(iv) Explain why at high energy states the probability function of electrons in a metal approaches the Maxwell-Boltzmann distribution of neutral gas.

[3 marks]

(b) For a particular semiconductor, the energy bandgap is $E_g = 1.50$ eV and $n_i = 10^5$ cm^{-3} at $T = 300$ K. Impurity atoms are added so that the Fermi energy level is 0.45 eV below the center of the bandgap. Assume that the effective mass of electron and hole at the band edge are the same and all impurity atoms are ionized.

(i) Are accepter or donor atoms added? Explain your answer. [2 marks]

(ii) What is the concentration of impurity atoms added? [3 marks]

(c) Consider a pure semiconductor sample with intrinsic free carriers concentration $n_i = 10^{10}$ cm^{-3}. If this sample is doped uniformly with phosphorus atoms to a concentration of 10^{16} cm^{-3} and simultaneously doped with an equal uniform concentration of boron atoms, explain why the free carrier concentration is still 10^{10} cm^{-3}.

[3 marks]

Continued....

Question 3

(a) The E-k diagram in Figure Q3 shows the first conduction band and valence band of a semiconductor. Using this diagram to answer the following questions:

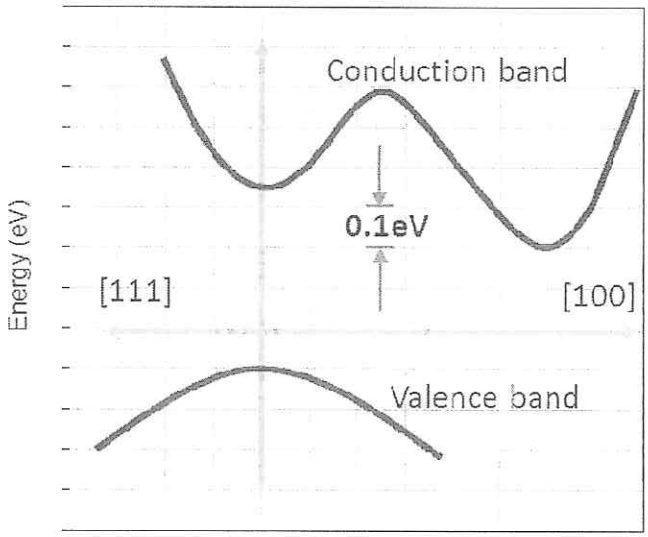

Figure Q.3

(i) Is the semiconductor energy gap direct or indirect? [1 mark]

(ii) What is the energy gap of the semiconductor? [2 marks]

(iii) Sketch the E-k diagram and in your diagram indicate the lowest energy state of an electron in the conduction band and the lowest energy of a hole in the valence band?

[2 marks]

(iv) The electrons or holes in a semiconductor can be described in a quasi-classical manner in the sense of Newton's law of motion through the use of effective mass. Show that this effective mass can be deduced from the energy-wavevector (E-k) diagram.

[7 marks]

(v) Explain which is lower, the hole or electron effective mass. [5 marks]

(b) With aid of diagrams, explain the difference between electron-hole recombination in direct and indirect semiconductors

[8 marks]

Continued....

Question 4

(a) Figure Q4 shows current (I)-voltage (V) characteristic of a semiconductor PN diode. Draw energy band diagrams of the PN junction under bias at point A, B, and C and explain the electron and hole currents flow across the junction. In your diagrams, show clearly the Fermi level throughout the junction in relation to the conduction and valence band edge.

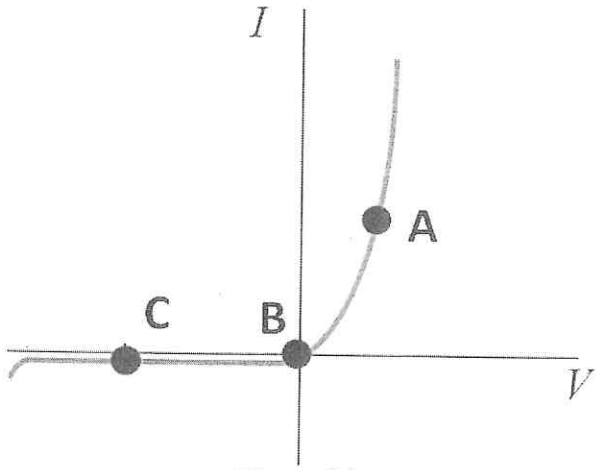

Figure Q4

[12 marks]

(b) A PN junction made from silicon with doping concentration of $N_A = 5\times10^{18}\,\text{cm}^{-3}$ on the p-side and $N_D = 2\times10^{16}\,\text{cm}^{-3}$ on the n-side is designed to operate at T = 300 K such that the diode current is I = 10 mA at a diode voltage of V = 0.5 V. Given that the intrinsic concentration, $n_i = 1.5\times10^{10}\,cm^{-3}$.

(i) Sketch the steady state electron and hole distributions in a forward biased PN junction. Indicate the excess minority electrons and holes in your diagram.

[5 marks]

(ii) Calculate the hole concentration just outside the depletion region on the n-region and the electron concentration just outside the depletion region on the p-region.

[4 marks]

(iii) Calculate the diode current for a reverse bias of 10 V. [4 marks]

End of the paper